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Dr. Robert A. Iacovazzi, Jr., Editor

Common Reference Channels for Metrological Comparability

In this article we discuss the effect of the choice of reference during calibration on later use of the calibrated results, and how a reference should be chosen to support later use of the data. Starting from the concept of metrological comparability we will formulate the purpose of calibration in metrology, and discuss the difference from a traditional (statistical) view. We derive some requirements for calibration, and especially for the choice of a useful reference. The calibration of a geosynchronous (GEO) instrument with a low spectral resolution against a low-earth-orbiting (LEO) instrument with a much higher spectral resolution used as a reference, as is currently done in GSICS, raises the question how the processing of the data from the reference sensor is affecting the aim of calibration.

One of the fundamental concepts in metrology is linked to the term *metrological comparability* (VIM 2008). It is always possible to compare any two numbers, but any pair of measurement results can only be compared if and only if they are traceable to the same unit(s) or reference(s). A prerequisite is that they share the same dimension. Comparability does not mean that the measurement results are of the same magnitude. For example the distance between the earth and the moon can be metrologically compared with a distance between two locations on earth if both distances are traceable to the same unit (SI meter definition).

One objective of the calibration of a measurement system is to establish a traceable link to a stated reference(s), which is important if one wants to use its results produced thereafter. One important use of measurement results is comparison and since comparison is only possible with common references, it is necessary to understand the usage of the results to determine a useful reference during calibration.

For all physical quantities that are part of the SI system of units, there is a developed and maintained system of reference standards available from the international network of standards organizations. For measurement systems being calibrated on Earth, the choice of reference is easy: one chooses the SI system of units whenever possible. Calibration services to support these references are available around the globe. These results are comparable in time and space (on Earth). As a result many quantities are currently metrologically comparable. But one should not forget that a huge effort is needed worldwide to establish and to maintain the SI system of units.

If one moves to outer space the choice of reference is not that easy, because calibration out there is not a simple service that can be bought from a provider. Calibration becomes a huge effort and simple concepts like regular re-calibration against arbitrary references are often close to impossible to implement.

Nevertheless, establishing a useful satellite inter-calibration system is a valuable mission. Without calibration one cannot metrologically compare any two results. So it is impossible to compare data from sensor A with data from sensor B, and if the data are not comparable then it is impossible to combine or verify the data. The ultimate consequence is that uncalibrated data is useless from a metrological point of view. Uncalibrated data might not even be comparable with itself in time if one does not have means to prove that a sensor is stable enough (not drifting).

For the inter-calibration of the GEO sensors (e.g., MSG) one can choose LEO sensors (e.g., IASI) as a reference. Figure 1 shows a block diagram of the metrologically relevant data processing of such a calibration. During the inter-calibration, collocations are chosen where the views of both sensors are sufficiently similar.

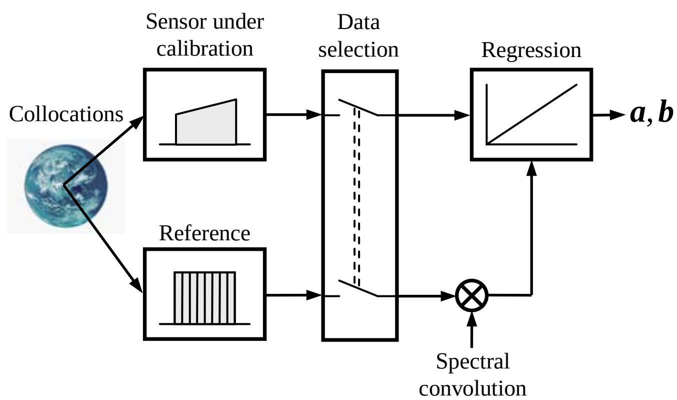

Figure 1: Block diagram of the metrological data processing for the inter-calibration of broad-band GEO sensors and high spectral resolution polar-orbiting sensors, such as IASI.

It can therefore be assumed that the sensor input to both sensors for any collocation is the same (within an uncertainty). A proper data selection method can ensure this. Since the spectral resolution of the two sensors is very different it is necessary to perform a spectral convolution in the data path of the high resolution reference sensor. A linear regression is used to combine the convoluted data from the reference sensor and the data from the sensor under calibration. The results are the offset *a* and the scale factor *b*.

The calibration parameters *a* and *b* are used later to correct the raw data of the calibrated sensor. The corrected data is then traceable to the reference results (IASI). The "accuracy" of the corrected results depends on the calibration of the reference sensor. Even if the reference sensor is uncalibrated but sufficiently stable then the calibrated (corrected) results traceable to the same reference are metrologically comparable.

Figure 2 shows a block diagram of the existing calibration scheme of the MSG sensors against IASI, flown on Metop. The spectral convolution in the reference path is "matched" to the particular sensor under calibration (MSG). This almost eliminates any spectral mismatch between reference sensor and the sensor under calibration.

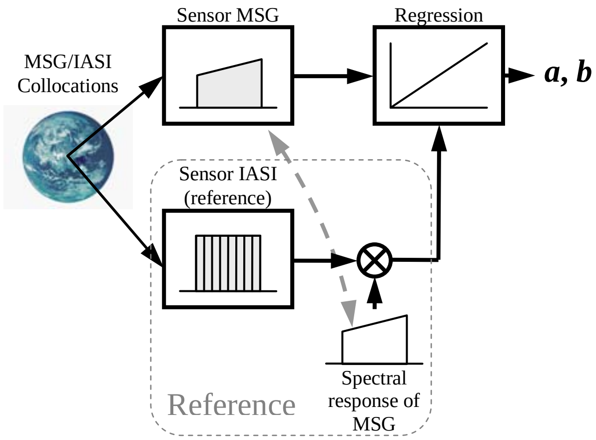

Figure 2: Existing calibration scheme of MSG sensors against IASI. The spectral convolution is "matched" to the individual MSG sensor.

However, since the matched spectral response is sensor specific, the reference for different sensors is systematically different and therefore the sensors are not traceable to the same reference. It is well known that one has to include a systematic error term because of the differences in the reference path when the results need to be compared. But the error term is unique for any pair of sensors and it is difficult to establish without detailed knowledge of the spectra of the sensor input.

But the corrected results based on this calibration are comparable to themselves and therefore it is possible with this kind of calibration to "transfer" the stability of the IASI sensor to the MSG results with the smallest possible uncertainty. This calibration method has an important value as long as the usage is limited to this case.

To achieve the goal of metrologically comparable results between different sensors, it is necessary to eliminate the sensor-specific processing in the reference path and to establish *Common Reference Channels* with a common spectral convolution for all sensors. Figure 3 shows the general calibration scheme where the processing of data in the reference path is independent of the sensor under calibration. The spectral convolution is reduced in this case to limiting the bandwidth.

The difference in the spectral response between the sensor path and the reference path causes what we call the *Spectral Mismatch* δL_r. The effect is dependent on the difference in the spectral response and the spectral variability of the target (Earth) for a given intensity or brightness temperature.

Because of the high spectral resolution of the reference sensor, some knowledge about the spectrum is available during calibration which can be used to evaluate an uncertainty specification (guard band) for the *Spectral Mismatch* δL_r. The associated uncertainty $u(\delta L_r)$ might dominate the final uncertainty in case that the sensor's Spectral Response Functions is significantly different from the spectral response in the reference path (e.g., flat top).

In case sensors with similar spectral response need to be compared, it might be useful to establish a common response in the reference path which matched the behaviour of the set of sensors more closely to reduce the uncertainty of the additional component δL_r for all sensors.

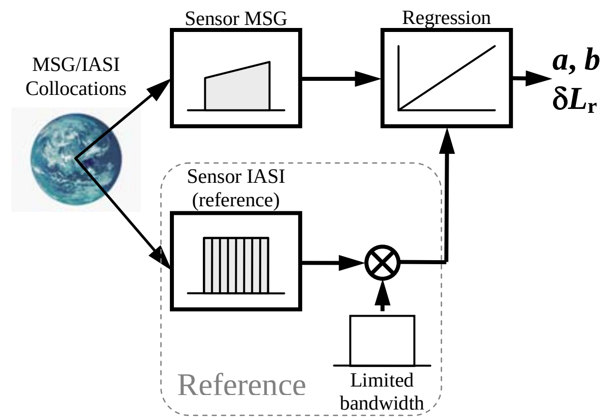

Figure 3: Proposed calibration scheme for MSG sensors against a polar-orbiting sensor (IASI). The spectral convolution is reduced to limit the bandwidth. δL_r is an additional component to describe the *Spectral Mismatch* and its uncertainty.

Until a system of standard references can be established in space for all quantities of interest, it might be useful to operate with multiple references here which can be defined on a practical basis. But it is important that the user clearly distinguishes them and that he does not compare "apples and oranges". One solution would be to provide the observations (raw data) and multiple calibration functions for different purposes and let the user apply the functions to the raw data. The user would be responsible for the application of the calibration and that the calibration matches the intended use of the measurement results.

Reference

BIPM 2008, International Vocabulary of Metrology – Basic and General Concepts and Associated Terms. VIM, 3rd edition, JCGM 200:2008. http://www.bipm.org

(by Dr. R. Kessel [NIST] and Dr. T.J. Hewison [EUMETSAT])

Defining Common Reference Channels for Geostationary Infrared Imagers

This article follows up the theoretical considerations presented above with an example applied to the infrared channels of geostationary imagers. The uncertainties, $u(\delta L_r)$, introduced by the process of spectral conversion to *Common Reference Channels* (CRCs) are evaluated and discussed. These are referred to *Spectral Mismatches.*

There are various ways to define CRCs for geostationary imagers. For example, it is possible to select one particular instrument as a reference – either in Geostationary or Low Earth Orbit. For example, defining a High-resolution InfraRed Sounder (HIRS) instrument allows the possibility of using a homogenised series of HIRS observations as inter-calibration references for historic archives of all geostationary imagers.

Another method is also investigated here, based on the definition of a synthetic CRCs, derived from the characteristics of combinations of the current geostationary imagers, comprising FY-2C, GOES-12, Meteosat-8 and MTSAT-1R. Synthetic CRCs are defined in bands where more than one of these instruments have channels. The CRCs are defined here to have simple, rectangular Spectral Response Functions (SRFs), whose limits are calculated as the mean wavelength at which the normalised SRFs of the constituent instruments cross 0.5. An example of this definition is shown in Figure 1.

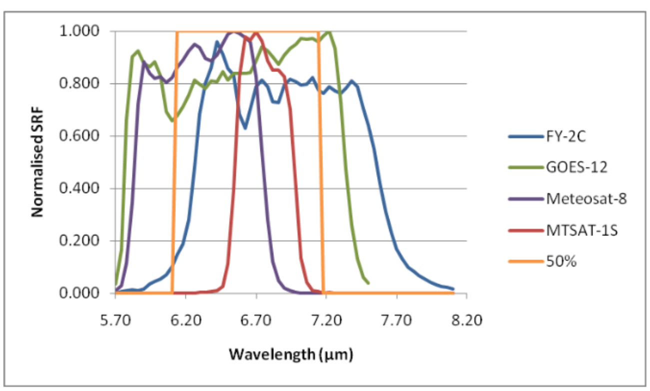

Figure 1: Spectral Response Functions of water vapour channels used to define rectangular *Common Reference Channel*, shown in orange as "50%"

Although this process is objective, the initial selection of the instrument/channel combinations introduces a subjective element in the analysis and the results will depend on this choice. For example, it would also be possible to combine multiple channels of a single instrument. However, the definitions should remain static for a given inter-calibration product.

To estimate the uncertainty introduced by the process needed to convert the radiances of the monitored instruments' channels to the CRCs, $u(\delta L_r)$, we evaluate the difference in radiances seen by these channels over a representative range of scenes. This is achieved by comparing a set of radiance spectra observed by the Infrared Atmospheric Sounding Interferometer (IASI) convolved with the monitored instrument's SRF and that of the CRC.

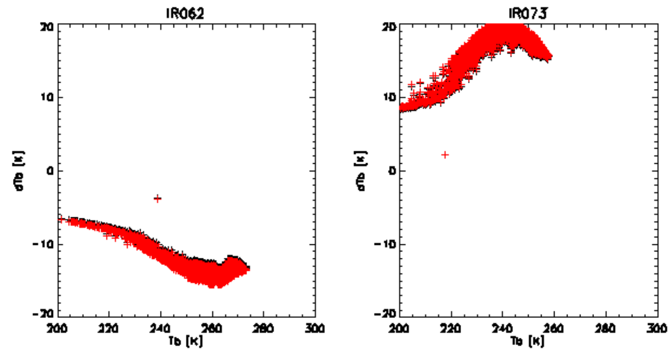

Figure 2: Spectral mismatches, δL_r, shown as brightness temperature differences [K] between water vapour channels of Meteosat-8 (black) and -9 (red) and Common Reference Channels.

The differences are plotted in Figure 2 for the two water vapour channels of Meteosat-8 and Meteosat-9. It can be seen that there are large differences (~10 K) between the radiances observed in these channels and those of the CRC. Although a spectral conversion process can account for the mean differences, a residual error remains, the *Uncertainty* associated with the *Spectral Mismatch* $u(\delta L_r)$, which introduces uncertainty into the inter-calibration product. The magnitude of this uncertainty is estimated in Table 1 as the standard deviation of the residuals from a quadratic fit through the radiances shown in Figure 2.

Table 1 - Residual errors introduced converting Meteosat/SEVIRI IR channels to *Common Reference Channel* and HIRS Channel - Spectral Mismatch Uncertainty, $u(\delta L_r)$.

Meteosat Second Generation Channel	CRC Wavelength Limits (µm)	CRC Spectral Mismatch Uncertainty, $u(\delta L_r)$	MetopA/ HIRS/4 Channel	HIRS Spectral Mismatch Uncertainty, $u(\delta L_r)$
IR3.9	3.619 - 4.072	0.72 K	17 19	1.12 K 1.02 K
IR6.2	6.101 - 7.152	0.73 K	12	0.88 K
IR7.3	6.383 - 7.493	1.10 K	11	0.16 K
IR8.7	(Meteosat Only)	(0.06 K)	N/A	N/A
IR9.7	(Meteosat Only)	(0.05 K)	9	0.06 K
IR10.8	10.301 - 11.336	0.03 K	8	0.42 K
IR12.0	11.461 - 12.521	0.10 K	8	0.87 K
IR13.4	12.801 - 13.870	0.08 K	7	0.29 K

Table 1 confirms our expectations that relatively large uncertainties are introduced by the spectral conversion process required when using these CRCs for channels in strongly absorbing parts of the spectrum, while minimal uncertainties are introduced for window channels. Table 1 also shows relatively large uncertainties introduced when using HIRS as reference channels – even in window regions, due to SRF differences. However, these may be sufficient quality for some applications, such as generating composite images from multiple GEO imagers.

More sophisticated definitions could be based on SRFs containing a certain fraction of the total radiance seen by each channel, or matching weighting functions, to more accurately reflect the response of channels in absorption bands. It may also be possible to define CRCs based by minimising the uncertainty associated with the spectral mismatch.

(by Dr. T.J. Hewison, [EUMETSAT] and Dr. R. Kessel, [NIST])

News in this Quarter

EO-1 Tenth Anniversary

On November 21, the Earth Observing One (EO-1) satellite completed 10 years of service. To commemorate the anniversary, a Gala Celebration took place on December 1st, 2010 at NASA Goddard Space Flight Center during an invitational three-day science retrospective symposium, featuring presentations from the EO-1 science team and other partners. More than 200 invitees from NASA centers, industry, academia, and national and international agencies participated in the events.

EO-1 originally flew at an altitude of 705 km in a formation with, and crossing the equator one minute after, Landsat 7. This formation was subsequently broken three years later, and currently EO-1 flies at 690 km. Data collected during the formation flying phase of the mission have allowed for cross comparisons of the instruments on both spacecrafts, and led to the establishment of the *AM Constellation*, the first *constellation* of Earth observing satellites (Landsat, EO-1, SAC-C, and Terra). The EO-1 mission has a number of notable accomplishments - many "firsts" in the areas of science validation, spacecraft bus technologies, and operations. For example, the EO-1 mission has generated a comprehensive spaceborne high spectral resolution imagery archive; implemented a shape memory alloy for a system hinge and deployment mechanism; and demonstrated that spaceborne hyperspectral imagers can identify and map vegetation species (see comprehensive list of EO-1 "firsts" at *http://eo1.gsfc.nasa.gov/new/general/firsts/poster.html*). The scientific data collection currently contains more than 51,000 archived images—used to study land cover spectral properties, diversity and ecosystem function, and catastrophic events such as floods, hurricanes, volcanoes and other disasters. EO-1 has two main instruments: the Advanced Land Imager (ALI) and the Hyperion imaging spectrometer. ALI has been used to demonstrate and validate remote-sensing capabilities that will be applied by the Landsat Data Continuity Mission (LDCM), and Hyperion is a heritage instrument for the Hyperspectral Infrared Imager (HyspIRI) mission, a NASA Tier 2 Decadal Survey mission recommended by the National Research Council in 2007. The EO-1's Hyperion is of particular interest to the GSICS community because of its ability to spectrally characterize ground calibration sites.

Hyperion is the only satellite sensor in civilian use that is acquiring continuous spectral imagery by observing the 400-2500 nm spectral range at 10 nm bandwidth and 30 m pixel size. As a result of its range of capabilities, Hyperion has become a critical data source for investigators conducting cutting-edge research in sensor comparisons and terrestrial ecological and geophysical studies around the world. The success of Hyperion has spawned the development of several state-of-the-art imaging spectrometers now planned for launch in 2011-2014 by international partners (e.g., Germany, Japan, Italy, and India). Thus, there is an international demand for Hyperion data in anticipation of those upcoming missions.

For representative calibration and instrumented vegetative sites, the EO-1 Mission Science Office at GSFC is collecting "spectral time series" of Hyperion data, to prototype science data products for future spectral missions. Hyperion data are collected and compiled by the EO-1 team for established validation and calibration sites characterization, in collaboration with ongoing international efforts such as the Committee on Earth Observing Satellites (CEOS), Global Earth Observing System of Systems (GEOSS), and the International Spaceborne Imaging Spectroscopy Working Group (ISIS WG), which provide forums for technical collaboration and programmatic discussion and consultation among national space agencies and research institutions. Hyperion's ability to image and spectrally characterize calibration sites, providing baseline spectral information for future comparisons is very useful for programs such as GSICS.

EO-1 10th Anniversary Gala at NASA/GSFC, from left to right Jay Perlman, Dan Mandl, Dale Schulz, Steve Ungar, Betsy Middleton, Garik Gutman and Dianne Wickland.

(by Drs. P. Campbell [UMBC] and E. Middleton [NASA])

GSICS Second Users' Workshop

The GSICS Second Users' Workshop was held on 21 September 2010 in Córdoba, Spain in coordination with the

EUMETSAT Satellite Conference. The meeting was convened as an effort for GSICS members to connect and communicate with current and potential GSICS users. The agenda of the meeting included updates from the GSICS Executive Panel, Coordination Center and Data and Research Working Groups. It also included progress statements from beta testers of current GSICS results. There was also discussion regarding the next steps that are to occur within GSICS, and between GSICS and the user community.

The initial presentations from the GSICS organization clarified to the user community the role of GSICS to inter-calibrate data from the global operational meteorological satellite system to traceable references – ultimately international standards (**S**ystème **I**nternational d'Unités). These brief talks also stressed the importance of establishing procedures to assure the quality of inter-calibration products that are distributed under the auspices of GSICS.

Most of the GSICS beta testers focused their presentations on the impacts of applying the GSICS GEO-LEO IR Correction to their products. In particular, these experiments assessed performance impacts of implementing the GSICS IR Correction to clear-sky radiance, cloud products (e.g., cloud mask, amount, and top height), and numerical weather prediction model simulations. These studies revealed positive impacts, some of which were significant. The results of the testing also revealed a need for better communication between GSICS and the organizations who volunteer as beta testers.

During the course of the workshop, users made requests to GSICS for :

- Improved calibration of GEO imager solar reflective channels;
- Inter-calibration of microwave instruments;
- Current and historical calibration of AVHRR; and
- Established quality flags for the current GSICS IR Correction.

Many of these activities are already on the immediate GSICS horizon. Other recommendations made by the users included inter-calibration corrections for historical GEO imager data, inter-calibration between infrared and microwave instruments, as well as improved image navigation and registration. Interest was also expressed that a procedure for product acceptance for research products be developed by GSICS. These suggestions were noted, and are to be considered within GSICS for possible future developments. In the end, GSICS panel members praised the users for their interest and beta testing efforts, as well as encouraged them to undertake new testing efforts. For more information regarding the GSICS Second Users' Workshop, please visit the GSICS wiki site at https://gsics.nesdis.noaa.gov/wiki/Development/UsersWorkshop2010.

(Dr. R. Iacovazzi (NOAA) and Dr. T. Hewison [EUMETSAT])

Just Around the Bend …

GSICS-Related Meetings

- **91st American Meteorological Society Annual Meeting,** 23-27 January 2011, Seattle, WA, USA
- **GPM X-Cal Meeting**, 1-2 March 2011, College Park, MD, USA
- **Joint GSICS Research Working Group VI and GSICS Data Working Group V Meeting**, 22-25 March 2011, Daejeon, South Korea

GSICS Publications

Xiong, X., C. Cao and G. Chander, 2010: An overview of sensor calibration inter-comparison and applications. *Frontiers Earth Sci. China*, **4**, No. 2, 237-252, DOI: 10.1007/s11707-010-0002-z

Please send bibliographic references of your recent GSICS-related publications to Bob.Iacovazzi@noaa.gov.

GSICS Classifieds

Submitting Classified Advertisements: Are you looking to establish a GSICS-related collaboration, or do you have GSICS-related internships, exchange programs, and/or available data and services to offer? *GSICS Quarterly* includes a classified advertisements section on an as-needed basis to enhance communication amongst GSICS members and partners. If you wish to place a classified advertisement in the newsletter, **please send a two to four sentence advertisement that includes your contact information to Bob.Iacovazzi@noaa.gov.**

With Help from our Friends:

The *GSICS Quarterly* Editor would like to thank those individuals who contributed articles and information to this newsletter. The Editor would also like to thank *GSICS Quarterly* Associate Editor, Gordana Sindic-Rancic of GCC, European Correspondent, Dr. Tim Hewison of EUMETSAT, and Asian Correspondent, Dr. Yuan Li of CMA, in helping to secure and edit articles for publication.

Submitting Articles to GSICS Quarterly: The *GSICS Quarterly* Press Crew is looking for short articles (<1 page), especially related to cal/val capabilities and how they have been used to positively impact weather and climate products. Unsolicited articles are accepted anytime, and will be published in the next available newsletter issue after approval/editing. **Please send articles to Bob.Iacovazzi@noaa.gov, *GSICS Quarterly* Editor.**